Influence of Commodity Type, Percentage of Cracked Kernels, and Wheat Class on Population Growth of Stored-Product Psocids (Psocoptera: Liposcelidae)

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ABSTRACT Differences in stored-product psocid progeny production as a function of commodity type, percentage of cracked kernels, and wheat class were examined using laboratory bioassays. Population growth of *Liposcelis bostrychophila* Badonnel, *Liposcelis decolor* (Pearman), *Liposcelis paeta* Pearman, and *Liposcelis entomophila* (Enderlein) (Psocoptera: Liposcelididae) was highest on sorghum *Sorghum bicolor* (L.) Moench, followed by wheat, *Triticum aestivum* L., and rice, *Oryza sativa* L., whereas progeny production was negligible on wheat germ. In a second experiment that did not include *L. entomophila*, population growth was examined on wheat containing 0, 1, 5, 10, 20, 50, and 100% cracked kernels. Progeny production did not increase as cracked kernel content increased. Instead, progeny production peaked at 20% for *L. bostrychophila* adults and nymphs, at 10% for *L. decolor*, and at 50% for *L. paeta* adults; no further increases were noted beyond these levels of cracked wheat content. In a third experiment that did not include *L. entomophila*, progeny production was examined on eight classes of wheat: hard red winter, hard red spring, soft white winter, soft white spring, soft club, durum, soft red winter, and hard white. Overall, progeny production was higher on durum wheat than on the other classes. The results indicate that there are considerable variations in psocid population growth among the different commodities tested, and this information may be used to predict the degree to which stored commodities are susceptible to psocid infestation.

KEY WORDS *Liposcelis*, varietal resistance, wheat classes

Stored-grain insects are generally polyphagous and can develop on a wide variety of grain-based commodities (Aitken 1975). However, some commodities are less vulnerable to infestation, a characteristic that is affected by several biochemical and physical parameters. These mechanisms may induce the biochemical attributes that can modify behavioral responses of a given insect (antixenosis) or affect its development (antibiosis) (Throne et al. 2000). However, varietal resistance mechanisms are poorly understood. For example, Amos et al. (1986) reported that protein content was negatively associated with progeny production for the rice weevil, *Sitophilus oryzae* (L.) (Coleoptera: Curculionidae), whereas Khokhar and Gupta (1974) found no correlation between protein content and *S. oryzae* progeny production. Similarly, kernel size and hardness play an important role in population growth of the lesser grain borer, *Rhyzopertha dominica* (F.) (Coleoptera: Bostrichidae), according to Amos et al. (1986), but they are not important according to other studies (McGaughey et al. 1990, Toews et al. 2000). Nevertheless, knowledge of the susceptibility level of commodities, e.g., wheat, *Triticum aestivum* L., varieties, can be used to predict dynamics of insect population growth in a given time period (Throne 1989).

Psocids are newly emerged pests of stored grains and related amylaceous commodities. They cause serious quantitative losses and qualitative degradation, and they are often found in extremely high numbers, particularly in grain bulks (Opit et al. 2009a,b). Apart from abiotic factors such as temperature and relative humidity, the type of commodity is determinative for psocid development (Rees and Walker 1990; Nayak and Collins 2001; Opit and Throne 2008a,b). However, most of the studies available on the influence of diet are focused on the effect of diet to enhance the laboratory rearing of psocids, but there is still inadequate information on the effect of types of grain, or grain characteristics, on progeny production. In the current study, we examined the effect of 1) commodity, particularly grain type; 2) percentage of cracked kernels; and 3) wheat class on the population growth of some

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of the most commonly found stored-product psocid pest species.

Materials and Methods

Psocid Species. Four psocid species were used in the tests: *Liposcelis bostrychophila* Badonnel, *Liposcelis decolor* (Pearman), *Liposcelis entomophila* (Enderlein), and *Liposcelis paeta* Pearman (Psocoptera: Liposcelididae), and voucher specimens were deposited in the Kansas State University Museum of Entomological and Prairie Arthropod Research (Manhattan, KS) under lots 182, 202, 205, and 207, respectively. All species were reared on a mixture of 97% cracked wheat kernels, 2% crisped rice breakfast cereals (Kellogg Company, Battle Creek, MI), and 1% brewer's yeast at 30°C and 70% RH, as suggested by Opit and Throne (2008b). Less than 4-wk-old adult females were used in the tests. The adults were handled according to the procedure described by Opit and Throne (2008b).

Bioassays. *Effect of Grain Commodities.* Untreated, clean, and infestation-free wheat (a mixture of the variety Fuller and Santa Fe); rice, *Oryza sativa* L. (variety Francis); oat, *Avena sativa* L. (variety Paul); sorghum *Sorghum bicolor* (L.) Moench (hybrid F1000); and maize, *Zea mays* L. (hybrid Golden Harvest H-8713), as well as wheat germ (Bob's Red Mill Natural Food, Milwaukie, OR) were used in the tests. Moisture content of the commodities was adjusted to 13.5% before the beginning of the experiments. To preclude incipient insect and mite infestations (also in the other two series of experiments), the commodities were kept in the refrigerator until the beginning of the experiments. Six hundred grams of each commodity was placed in 0.473-liter glass jars, and six 10-g samples were taken from each jar and placed in plastic cylindrical vials (3 cm in diameter, 8 cm in height). Hence, there were six replicates for each commodity. Then, five adult females of *L. bostrychophila* were placed in each vial. The same procedure was followed for the other species by taking new samples from the jars. The vials had a plastic lid with a hole in the center covered with a U.S. #40 fine mesh screen (0.42-mm openings). The top one quarter of the inside of each vial was covered by Fluon (Northern Products, Woonsocket, RI) to prevent psocids from escaping. All vials were then placed randomly in black plastic boxes with a saturated sodium chloride solution to maintain 75% RH (Greenspan 1977). The boxes were then placed in incubators set at 30°C and 75% RH. The vials were opened after 35 d, and the numbers of live adults and nymphs were recorded.

Effect of Cracked Wheat Kernels. Only *L. bostrychophila, L. decolor,* and *L. paeta* were used in this experiment. A mixture of the wheat varieties Fuller and Santa Fe, adjusted to 13.5%, was used. Seven jars containing 0, 1, 5, 10, 20, 50, and 100% cracked kernels were prepared. The wheat was cracked as suggested by Opit and Throne (2008a). Materials and methods were similar to those in the previous experiment; each treatment had six vials (six replicates).

Effect of Wheat Class. Only *L. bostrychophila, L. decolor,* and *L. paeta* were used in this experiment. Eight different classes of wheat (adjusted to 13.5%) were evaluated: 1) hard red winter wheat (variety Newton); 2) hard red spring wheat (variety Kulm); 3) soft white winter wheat (variety Madsen); 4) soft white spring wheat (variety Alpowa); 5) soft white winter club wheat (variety Tres); 6) durum wheat (unknown variety, originated from El Toro, CA); 7) soft red winter wheat (variety Caldwell-Ohio); and 8) hard white wheat (variety Blanca Grande). Sample arrangement, conditions, and progeny measurement were as described above.

Data Analysis. Data were analyzed separately for each experiment, species, and life stage (adults or nymphs) by using a one-way analysis of variance (ANOVA) (Sall et al. 2001). Before the analysis, all data sets were submitted separately to Levene test, to examine the homogeneity of variances. When variances were not equal, the data were transformed to arc-tangent scale (indicated in the tables). Means were separated by using the Tukey–Kramer honestly significant difference (HSD) test at 0.05.

Results

Effect of Grain Commodities. The highest number of progeny was recorded for *L. entomophila* and the least for *L. decolor* (Table 1). The greatest numbers of *L. bostrychophila* adult progeny were found on wheat and sorghum, and no adult progeny were found on wheat germ. The only commodity where >70 *L. bostrychophila* nymphs per vial were found was on sorghum; progeny nymphs did not exceed 31 individuals per vial in the other commodities, and no nymphs were found on wheat germ. Significantly more *L. decolor* adult progeny were found on oat and sorghum than on the other four commodities, although adult progeny production never exceeded 20 individuals. No significant differences were noted among commodities for *L. decolor* nymphs. More *L. paeta* adults and nymphs were found on wheat, rice, and sorghum, although adult progeny production never exceeded 32 individuals. More than 100 *L. entomophila* adults were recorded on wheat and sorghum, and the number of adults on wheat germ was negligible. The highest number of *L. entomophila* nymphs was recorded on sorghum, and no nymphs were found on wheat germ.

Effect of Cracked Wheat. Overall, more progeny were found for *L. bostrychophila* than for the other two species tested (Table 2). For this species, significant differences in the numbers of adults were noted only between whole wheat and wheat containing 20% cracked kernels. Similarly, significantly more *L. bostrychophila* nymphs were recorded in vials containing 20% cracked wheat than in vials with other percentages of cracked wheat. The increase in *L. decolor* adult progeny with increase in cracked wheat content was not pronounced. However, significantly

Table 1. Progeny production, expressed as number of adults or nymphs/vial (mean ± SE), of four *Liposcelis* psocid species on different commodities (within each column, means followed by the same letter are not significantly different; HSD test at 0.05, in all cases df = 5,30)[a]

Commodity	*L. bostrychophila*		*L. decolor*		*L. paeta*		*L. entomophila*	
	Adults	Nymphs	Adults	Nymphs	Adults	Nymphs	Adults	Nymphs
Wheat	55.8 ± 7.1a	25.7 ± 3.1b	8.7 ± 2.6b	13.3 ± 4.4a	31.8 ± 7.4a	20.0 ± 7.1a	106.2 ± 9.2a	76.0 ± 13.1b
Rice	40.7 ± 8.4ab	30.7 ± 13.2b	7.8 ± 2.9b	8.0 ± 2.3a	27.8 ± 6.9ab	20.3 ± 5.6a	93.7 ± 10.5ab	52.2 ± 10.6b
Oat	24.8 ± 9.0bc	10.0 ± 2.6b	20.7 ± 3.3a	14.5 ± 4.2a	2.7 ± 2.1c	2.7 ± 2.7b	60.5 ± 15.7b	48.0 ± 10.7b
Sorghum	62.5 ± 5.6a	70.5 ± 13.8a	20.2 ± 2.8a	17.5 ± 3.3a	19.5 ± 2.4ab	19.3 ± 4.8a	127.0 ± 11.0a	118.1 ± 10.5a
Maize	12.8 ± 3.5c	13.2 ± 6.1b	6.2 ± 1.3b	9.5 ± 3.0a	9.8 ± 1.8bc	5.8 ± 1.8b	29.7 ± 6.8c	27.3 ± 7.6c
Wheat germ	0.0 ± 0.0d	0.0 ± 0.0c	5.2 ± 0.7b	4.0 ± 0.9a	6.2 ± 0.9c	3.7 ± 0.8b	0.2 ± 0.2d	0.0 ± 0.0d
F	14.7	11.4	3.8	0.7	7.3	4.0	23.2	17.8
P	<0.01	<0.01	<0.01	0.58	<0.01	<0.01	<0.01	<0.01

[a] Data were arc-tangent transformed only for *L. decolor* adults and nymphs (Levene's test for *L. bostrychophila*, adults $F = 3.7$, $P < 0.01$ and nymphs $F = 6.5$, $P < 0.01$; for *L. decolor*, adults $F = 1.9$, $P = 0.12$ and nymphs $F = 1.8$, $P = 0.13$; for *L. paeta*, adults $F = 7.1$, $P < 0.01$ and nymphs $F = 4.7$, $P < 0.01$; and for *L. entomophila*, adults $F = 4.0$, $P < 0.1$ and nymphs $F = 4.2$, $P < 0.01$. In all cases, df = 5.30 (untransformed values are presented in the table).

more adults and nymphs were recorded in vials containing 10% or more cracked wheat than in vials containing whole kernels. No significant differences were noted among treatments for *L. decolor* adults or nymphs.

Effect of Wheat Class. Significantly more *L. bostrychophila* adults were recorded on durum wheat than on the other wheat classes, whereas the lowest number of adults was found on hard red winter and soft white spring wheat (Table 3). The highest numbers of *L. bostrychophila* nymphs were found on durum wheat and soft white club. Significantly more *L. decolor* adults and nymphs were found on durum wheat than on other wheat classes, and the lowest number of progeny was found on hard red winter wheat. Similarly, the number of *L. paeta* adult progeny was much higher on durum wheat than on the other classes of wheat. However, no significant differences were recorded among wheat classes for *L. paeta* nymphs.

Discussion

Our study demonstrates that psocids can develop high population densities, even during a short 35-d interval, in a large variety of amylaceous products. This observation is indicative of their wide food preferences. Numbers of adult psocids increased by as much as 25-fold from an initial population of five females in some of the commodities used in our study. However, population growth was influenced by the type of commodity and the psocid species. Based on our results, psocids can be considered capable of surviving and reproducing on whole kernels, for all the grain commodities examined. This characteristic is particularly important, given that insect species that are able to feed on sound raw grain kernels pose a greater economic risk in grain bulks compared with species that require the presence of cracked kernels. Other studies have also shown that psocids can damage sound kernels (Rees and Walker 1990, Kurová 1999). According to Kučerová (2002), weight loss in stored grain due to psocid infestations can exceed 10%. Opit and Throne (2008b) noted that *L. entomophila* and *Lepinotus reticulatus* Enderlein (Psocoptera: Trogiidae) could develop on several grain commodities, but population growth varied among commodities. They noted that maize was less suitable than wheat, rice, barley (*Hordeum vulgare* L.), sorghum, or oat for *L. reticulatus*, whereas wheat, barley, and sorghum were more suitable than oat, rice, and maize for *L. entomophila*. Our results are partially in agreement

Table 2. Progeny production, expressed as number of adults or nymphs/vial (mean ± SE), of three *Liposcelis* psocid species on wheat containing different percentages of cracked kernels (within each column, means followed by the same letter are not significantly different; HSD test at 0.05, in all cases df = 6, 35)[a]

% cracked	*L. bostrychophila*		*L. decolor*		*L. paeta*	
	Adults	Nymphs	Adults	Nymphs	Adults	Nymphs
0	67.3 ± 14.7b	85.8 ± 15.1b	15.7 ± 3.9b	8.3 ± 1.8c	26.7 ± 3.7a	31.8 ± 4.5a
1	94.6 ± 10.2ab	64.7 ± 6.4b	21.2 ± 5.8ab	14.0 ± 4.5bc	32.5 ± 7.2a	71.6 ± 38.1a
5	94.8 ± 5.7ab	115.7 ± 25.1b	27.3 ± 3.4ab	17.5 ± 5.6bc	27.2 ± 4.3a	28.6 ± 5.3a
10	86.0 ± 8.5ab	124.0 ± 18.2b	35.0 ± 5.2a	33.0 ± 10.1ab	36.7 ± 5.9a	56.1 ± 8.9a
20	122.5 ± 9.6a	280.8 ± 57.5a	39.3 ± 7.2a	48.5 ± 15.6a	30.8 ± 4.6a	59.8 ± 10.9a
50	71.2 ± 12.8ab	129.2 ± 17.4b	43.5 ± 7.7a	54.0 ± 13.7a	61.2 ± 12.4a	55.8 ± 11.9a
100	111.7 ± 12.1ab	100.2 ± 11.1b	35.2 ± 6.6a	58.3 ± 14.6a	24.8 ± 5.9a	50.8 ± 13.9a
F	2.8	7.1	3.0	3.6	1.3	0.8
P	0.02	<0.01	0.01	<0.01	0.29	0.57

[a] Data were arc-tangent transformed only for *L. bostrychophila* adults, *L. decolor* adults, and *L. paeta* adults (Levene's test for *L. bostrychophila*, adults $F = 0.9$, $P = 0.49$ and nymphs $F = 3.4$, $P < 0.01$; for *L. decolor*, adults $F = 0.9$, $P = 0.53$ and nymphs $F = 2.4$, $P = 0.04$; for *L. paeta*, adults $F = 1.7$, $P = 0.15$ and nymphs $F = 2.9$, $P = 0.02$). In all cases, df = 6.35 (untransformed values are presented in the table).

Table 3. Progeny production, expressed as number of adults or nymphs per vial (mean ± SE), of three psocid species on different classes of wheat (within each column, means followed by the same letter are not significantly different; HSD test at 0.05, in all cases df = 7, 40)[a]

Class of wheat	*L. bostrychophila*		*L. decolor*		*L. paeta*	
	Adults	Nymphs	Adults	Nymphs	Adults	Nymphs
Hard red winter	21.0 ± 4.9d	28.5 ± 6.2c	4.5 ± 2.0d	7.2 ± 2.9d	41.3 ± 7.1d	65.8 ± 5.7a
Hard red spring	58.2 ± 14.1b	67.3 ± 15.8b	8.0 ± 2.4cd	9.2 ± 3.4cd	63.0 ± 7.9cd	48.3 ± 6.2a
Soft white winter	61.7 ± 11.4b	44.5 ± 6.2bc	23.7 ± 3.8b	18.0 ± 3.2bc	63.0 ± 11.5cd	97.3 ± 29.9a
Soft white spring	28.2 ± 3.6cd	44.3 ± 3.3bc	26.8 ± 5.2b	26.3 ± 5.1b	71.0 ± 8.9bc	73.2 ± 7.3a
Soft white club	42.5 ± 8.2bc	93.2 ± 2.6a	15.3 ± 3.4c	13.2 ± 3.1cd	77.5 ± 9.4b	79.5 ± 10.9a
Durum	100.5 ± 8.6a	99.7 ± 7.1a	94.7 ± 5.7a	51.6 ± 4.6a	132.5 ± 18.3a	80.0 ± 9.1a
Soft red winter	40.3 ± 5.0bc	55.3 ± 5.5b	16.7 ± 4.9c	10.8 ± 4.3cd	54.8 ± 4.5cd	59.0 ± 6.9a
Hard white	54.3 ± 9.6b	57.7 ± 8.7b	14.5 ± 3.1c	9.3 ± 2.1cd	50.6 ± 8.6cd	38.3 ± 6.9a
F	6.8	9.6	2.4	9.6	3.4	2.2
P	<0.01	<0.01	0.03	<0.01	0.01	0.06

[a] Data were arc-tangent transformed only for *L. bostrychophila* adults, *L. decolor* adults, and nymphs, and *L. paeta* adults (Levene's test for *L. bostrychophila*, adults $F = 1.6$, $P = 0.16$ and nymphs $F = 2.9$, $P < 0.01$; for *L. decolor*, adults $F = 1.5$, $P = 0.17$ and nymphs $F = 1.3$, $P = 0.26$; for *L. paeta*, adults $F = 1.7$, $P = 0.13$ and nymphs $F = 3.9$, $P < 0.01$). In all cases, df = 7, 40 (untransformed values are presented in the table).

with those of Opit and Throne (2008b), given that *L. entomophila* population growth was found to be higher on wheat and sorghum, than on maize and oat. Taking into account the combined progeny data, although each species had different population growth trends, sorghum was suitable for all species. As expected, psocid development was extremely poor on wheat germ. This is because the germ of cereals are high in protein, lipid, mineral (ash), and vitamins but are devoid of starch (Hoseney and Faubion 1992), which is vital for energy provision. Addition of wheat germ to psocid diets made of cracked grain alone may boost population growth by providing additional high levels of nutrients (G.P.O., unpublished data).

The presence of cracked wheat resulted in increased progeny production in the species tested. The effect of cracked kernels was more pronounced for *L. bostrychophila*. However, the gradual increase in cracked wheat content was not linearly correlated with progeny increase, suggesting that there is a critical cracked wheat content that enhances population growth, and that higher cracked wheat contents may have an adverse effect on survival or progeny production. Based on the overall progeny data, 20% cracked wheat content can be considered as "critical" given that further increase negatively affects population growth. For laboratory rearing of *L. bostrychophila*, *L. paeta*, and *L. entomophila*, Nayak and Collins (2001) proposed a diet based on a mixture of whole wheat, kibbled (cracked) wheat, and wheat flour. For *L. entomophila*, Opit and Throne (2008b) noted that population increase was higher on cracked wheat than on a diet based on 97% cracked wheat, 2% rice krispies, and 1% brewer's yeast (wt:wt). In that study, the authors reported that there is an inverse relationship between psocid population growth and diet compactness, which may explain the lack of a linear correlation between psocid population growth and the percentage of cracked wheat present above a certain cracked wheat percentage. Diet compactness would be expected to be directly proportional to the percentage of cracked kernels present in a given diet.

Our results suggest that, for *L. decolor*, the increase in cracked wheat content is positively associated with increase in progeny production, especially for progeny nymphs. For example, the population (adults + nymphs) increased ≈18-fold from an initial population of five females in vials containing 100% cracked wheat. Generally, population growth was poor on a diet containing no cracked wheat. Population growth of *L. paeta* was increased at cracked wheat content of 50% and then declined at 100% cracked wheat content. Our results show that there were different population growth trends between adults and nymphs for all three psocid species. The population of *L. paeta* adult progeny was higher in some cracked wheat and wheat class categories, whereas no such differences were noted for nymphs. This observation may indicate that diet differences may reflect differences in developmental parameters, which indirectly enhance a faster egg-to-adult development. Opit and Throne (2008b) noted that sex ratio differed among diets and that the proportion of females was higher in diets that were less suitable for development. In our study, the diets that were more suitable resulted in higher numbers for both adults and nymphs. The influence of diet on developmental parameters has been recorded for other stored-product insects (Meagher et al. 1982, Throne and Culik 1989, Throne et al. 2000, Toews et al. 2000, Chanbang et al. 2008). For example, Meagher et al. (1982) found that population growth of the maize weevil, *Sitophilus zeamais* Motschulsky (Coleoptera: Curculionidae), was similar on whole millet and millet containing 10% cracked kernels, whereas a diet of 100% cracked kernels was more suitable for the red flour beetle, *Tribolium castaneum* (Herbst) (Coleoptera: Tenebrionidae). Similarly, Throne and Culik (1989) noted that development of the rusty grain beetle, *Cryptolestes ferrugineus* (Stephens) (Coleoptera: Laemophloeidae), was faster on cracked than on whole maize.

Classes of wheat vary considerably in their chemical composition, and also in other nonchemical characteristics such as kernel hardness, density, and size

(Pomeranz et al. 1988, McGaughey et al. 1990). The class of wheat is an important parameter, often determinative for both insect development and insecticidal efficacy. For example, McGaughey et al. (1990) compared the susceptibility of five classes of wheat to infestation by *S. oryzae* and *R. dominica* and found that kernel size and density did not correlate well with the population growth of either species. However, kernel hardness was an important criterion for *S. oryzae* but not for *R. dominica* (McGaughey et al. 1990). In light of our findings, durum wheat was overall more suitable than the other wheat classes for the population growth of *L. bostrychophila, L. decolor,* and *L. paeta.* Generally, durum wheat has higher kernel hardness, kernel size, and protein content compared with some of the other wheat classes (McGaughey et al. 1990, Toews et al. 2000). However, for *R. dominica,* Toews et al. (2000) found that there is no correlation between progeny production and protein content or kernel hardness, but they found that kernel size was negatively correlated with progeny production. In our study, similar numbers of *L. bostrychophila* nymphs were produced on soft white club and durum, but adult numbers in durum were significantly higher than those in other wheat classes. Moreover, wheat class had no effect on *L. paeta* nymph population. As noted above, certain physical and chemical characteristics may accelerate development to the adult stage. Taking into consideration the above-mentioned observations, the rearing medium on which the parental individuals had been reared before their introduction to the different diets may influence their longevity and fecundity parameters in an equally important degree with the influence of a given diet to egg hatching and immature development. However, it should be noted that these present data are indicative only in the case of the varieties tested and should not be generalized among wider groups of commodities, such as classes of wheat or grain species.

Varietal resistance is one of the basic components that should be seriously taken into account when a stored-product integrated pest management-based strategy is planned (Throne et al. 2000). The results of the current study could be practically used in this effort, because the grain type, and some of its characteristics, such as the proportion of cracked kernels, can be used as indicators to predict the degree to which certain commodity is susceptible to psocid infestation. Additional studies are needed to determine the potential mechanisms that affect this susceptibility and their interactions with psocid biological parameters.

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